

## **The Properties of Convective Clouds Over the Western Pacific and their Relationship to the Environment of Tropical Cyclones**

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### **LONG-TERM GOALS**

The long-term goal of the proposed work is to advance our understanding of the relationship between large-scale and mesoscale environmental conditions and small but powerful convective events during tropical cyclone (TC) development and intensity changes. Our ultimate goal is to identify the necessary conditions that determine the formation and evolution of a TC.

### **OBJECTIVES**

With the data obtained during ONR's field program of "Tropical Cyclone Structure 2008 (TCS-08)" over the western Pacific region, the objective of this proposed study is to investigate large-scale environmental conditions, mesoscale phenomena and small scale convective bursts as well as their interactions that are responsible for TC formation and intensity changes. Specific areas include 1) Characterize the intensity of convection over the western Pacific oceans from radar, aircraft and satellite data; 2) Derive an accurate mesoscale environment of convective systems through the assimilation of satellite, radar, lidar and in-situ data; 3) Evaluate the quality of the global forecast system (e.g., Navy Operational Global Atmospheric Prediction System or NOGAPS) for accurate TC analyses and forecasts; 4) Understand the environmental factors that determine tropical cyclone formation and rapid intensification.

### **APPROACH**

In order to achieve the research objectives of this proposal, our approach integrates observational data analysis, mesoscale data assimilation and forecast evaluations. This includes 1) analyzing TCS-08 field data in conjunction with the available satellite data products from the NASA Aqua and Tropical Rainfall Measuring Mission (TRMM), 2) Using mesoscale numerical simulations with assimilation of satellite, radar, lidar and in-situ data into the Weather Research and Forecasting (WRF) and the

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Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS®) mesoscale models, and 3) evaluating the performance of global ensemble forecasting to understand the quality of global forecasts and also study the predictability of TC formation and evolution.

People involved in this project in FY11 include the PI (Prof. Zhaoxia Pu), her graduate students (Levi Thatcher and Zhan Li) and NRL collaborators (Drs. Carolyn Reynolds and Allen Zhao).

## WORK COMPLETED

Works completed in FY11 include:

- Continued on mesoscale numerical simulations of TCS-08 typhoons with assimilation of satellite, radar and in-situ observations.
- Characterized the convective properties in developing and non-developing tropical waves with radar observations during TCS-08.
- Developed a software package to automatically track the genesis and evolution of the TC genesis and evolution in global ensemble forecasting.
- Studied the TC cloud and precipitation characteristics using 10 years of TRMM satellite observations.

## RESULTS

### (1) *Impact of assimilation of airborne Doppler radar on numerical simulation of tropical cyclones*

Research activities have been continued on assimilating satellite, radar and in-situ observations for improved numerical simulations of major Typhoons (Jiangmi, Sinlaku, Nuri and Hagupit) during T-PARC/TCS-08 field experiment. In FY 11, the major emphasis was given to 1) airborne Electra Doppler RAdar (ELDORA) data quality control and 2) radar data assimilation.

Following the progress last year, work has been continued on examining the impact of the ELDORA radar data quality control on assimilating airborne Doppler radar reflectivity and radial velocity in numerical simulations of Typhoon Jangmi (2008). Specific attention was paid to evaluate the impact of error characteristics of radar data on data assimilation and numerical simulations of TCs with comprehensive numerical experiments. In addition to the findings from last year, it is found that the impact of assimilating radar reflectivity is smaller than that of assimilating radar radial velocity. The possible cause of this problem is further investigated. It is recommended that a lack of the attenuation correction may be one of the limitations in current radar reflectivity data quality control and assimilation. Further study in this direction is necessary in the future investigation.

### (2) *Characterize the convective properties in developing and non-developing tropical waves with radar observations*

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Characteristics of convective properties associated with two tropical waves (pre-genesis and genesis phases of Typhoon Nuri and a non-developing tropical wave TCS-30) during TCS-08 are examined and compared with ELDORA radar reflectivity and vertical velocities derived from the radar radial velocities. Preliminary findings are the following: in the developing case (Nuri), intense hot towers were observed. They were distributed systematically close to the circulation center. Strong convection was initiated and organized in the major mesoscale convection system (MCS) region to enhance the tropical depression; In contrast, in the non-developing case (TCS-30), intense convective bursts were scattered out of the major MCS region. There were also not intense and organized convections near the major MCS region.

Characteristics of the convective properties in various developing phases of Typhoon Nuri were also examined. It is found that: in the rapid intensification phase, organized convective structures presented in the inner rainband. Specifically, the convection was initiated at the front edge of the rainband in low levels, while the convective flow was intensified and grew much higher at the middle part of the rainband. In the outer rainband, scattered convective bursts were distributed with quite intense updraft (over  $10 \text{ m s}^{-1}$ ) and high echo top. In the mature stage, a double-eyewall structure was observed. The inner eyewall was totally dominated by the upward flow. The outer eyewall showed even more intense convection with stronger updraft and higher echo top.

### *(3) Further development in tracking the tropical cyclogenesis and evolution in global ensemble forecasts*

Following the efforts in last two years, studies have been continued on evaluating the NOGAPS ensemble forecasts for their abilities in predicting TC formation. Specifically, considering the previous manual tracking method is relatively labor intense for ensemble evaluations, further development was conducted to automate the TC tracking process. We adopted the GFDL vortex tracking software package (developed by T. Marchock) as a basic framework. The following additional modifications to the software have been made: 1) adding Fortran programs to calculate and write out key parameters for TC genesis study; 2) making new shell scripts to run the software package for large ensemble forecasts. These new additions enabled the software package to be able to apply for automatically tracking the genesis and evolution of TCs in global ensemble forecasts. It is anticipated that the software package will particularly improve the efficiency of tracking the TC genesis and evolution in large ensembles. Further test is in progress.

### *(4) Tropical cyclone cloud and precipitation characteristics*

The question of how precipitation and cloud structures vary from the tropics in general to the TC environment has not been fully explained. This type of study is important because accurate forecast of TCs by numerical models depends on our understanding of the TC's cloud and precipitation structures. As a follow-up of previous case studies, a study is conducted to examine if, and how, precipitating TC cloud characteristics differ from general precipitating tropical clouds. This is done using the data from 10 years (1998-2007) of TRMM precipitation radar (PR, the first radar in space and was designed to provide a vertical distribution of rainfall over the tropics) data over the West Pacific region ( $10\text{-}30^\circ\text{N}$  and  $130\text{-}150^\circ\text{E}$ ). Using the University of Utah's precipitation feature (PF) database, the differences between tropical and TC related PFs were analyzed in terms of their area, cloud top height, and precipitation contribution. Results indicated that in TC environments cumulus congestus-related (5-10km height) radar echoes occur significantly more frequently than they do in the general West Pacific

tropical environment. The increase in TC-related congestus is most notable around the 5.5 km height level, but persists up to around 10km and is persistent throughout the 10-year sample. This difference is possibly due to enhanced levels of ice in TC environments and stabilized melting level that forms because of melting. As expected, in TC environments rainfall is more concentrated in large, tall PFs (i.e., cumulonimbus) than in the tropics in general. Detailed analysis is in progress.

## IMPACT/APPLICATIONS

The data analysis, numerical simulations and data assimilation help understanding of the environmental conditions that contribute to TC genesis and rapid intensification. The evaluation of the performance of NOGAPS ensemble forecasts of TCs will be helpful for the future development and improvement of ensemble forecast systems.

## PUBLICATIONS

### (1) Peer-reviewed journal articles

- Thatcher, L., Y. Takayabu, C. Yokoyama, Z. Pu, 2011: Precipitating tropical cyclone characteristics (under preparation).
- Thatcher, L. and Z. Pu, 2011: How vertical wind shear affects the rapid intensification of Typhoon Jangmi (2008). Submitted to *Mon. Wea. Rev.*
- Zhang L., Z. Pu, W.-C. Lee, and Q. Zhao, 2010: The influence of airborne Doppler radar data quality control on numerical simulations of a tropical cyclone. *Wea. Forecasting* (Conditionally accepted).
- Snyder, A., Z. Pu , and C. A. Reynolds, 2011: Impact of stochastic convection on ensemble forecasts of tropical cyclone development. *Mon. Wea. Rev.*, **139**, 620-626.
- Pu, Z., and L. Zhang, 2010: Validation of AIRS temperature and moisture profiles over tropical oceans and their impact on numerical simulations of tropical cyclones, *JGR-Atmosphere*, **115**, D24114, doi: 10.1029/2010JD014258

### (2) Book Chapters

- Pu, Z., 2011: Improving Hurricane Intensity Forecasting through Data Assimilation: Environmental Conditions Versus the Vortex Initialization, *Recent Hurricane Research - Climate, Dynamics, and Societal Impacts*, Anthony Lupo (Ed.), ISBN: 978-953-307-238-8, InTech. [Available online: <http://www.intechopen.com/books/show/title/recent-hurricane-research-climate-dynamics-and-societal-impacts> ]
- Thatcher, L. and Z. Pu, 2011: How vertical wind shaer affacts tropical cyclone intensity change: An overview(Book Chapter). *Recent Hurricane Research - Climate, Dynamics, and Societal Impacts*, Anthony Lupo (Ed.), ISBN: 978-953-307-238-8, InTech. [Available online: <http://www.intechopen.com/books/show/title/recent-hurricane-research-climate-dynamics-and-societal-impacts> ]

(3) *Conference papers and presentations*

- Pu, Z., L. Zhang, Z. Li, 2011 (*Invited presentation*): Numerical simulations of tropical cyclones with assimilation of satellite, radar and in-situ observations: lessons learned from recent field programs and real-time experimental forecasts. *8<sup>th</sup> Annual meeting of Asia Oceania Geosciences Society (AOGS)*, August 8-12, 2011, Taipei, Taiwan.
- Pu, Z. and Z. Li, 2011: Examination of the role of intense convection in tropical cyclone formation. *14<sup>th</sup> AMS Conference on Mesoscale Processes*. August 1-4, 2011, Los Angeles, CA.
- Thatcher, L., Y. Takayabu, C. Yokoyama, Z. Pu, 2011: What TRMM tells us about precipitating TC cloud characteristics. *Tenth Annual Student Conference*. 91<sup>st</sup> AMS annual meeting. January 23-27, 2011, Seattle, WA
- Li, Zhan, Z. Pu and Wen-Chau Lee, 2011: Characteristics and structures of precipitation associated with tropical cyclone intensity changes. *Tenth Annual Student Conference*. 91<sup>st</sup> AMS annual meeting. January 23-27, 2011, Seattle, WA
- Thatcher, L. and Z. Pu, 2011: How vertical wind shear affects the intensification of Typhoon Jangmi (2008). *24th Conference on Weather and Forecasting/20th Conference On Numerical Weather Prediction*. 91<sup>st</sup> AMS annual meeting. January 23-27, 2011, Seattle, WA
- Emmitt, G. D., Z. Pu, K. Godwind, and S. Greco, 2011: Airborne Doppler Wind Lidar data impacts on tropical cyclone track and intensity forecasting: the data processing, interpretation and assimilation. *15<sup>th</sup> Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS)*. 91<sup>st</sup> AMS annual meeting. January 23-27, 2011, Seattle, WA
- Pu, Z. and L. Zhang, 2011: Numerical simulations of tropical cyclones with assimilation of satellite, radar and in-situ observations: lessons learned from recent field programs and real-time experimental forecasts. *15<sup>th</sup> Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS)*. 91<sup>st</sup> AMS annual meeting. January 23-27, 2011, Seattle, WA
- Pu, Z., and L. Zhang, 2010: Numerical simulations of tropical cyclones with assimilation of satellite, radar and in-situ observations: lessons learned from recent field programs and real-time experimental forecasts. *AGU Fall Meeting*, December 13-17, 2010, San Francisco, CA
- Pu, Z., 2010: HFIP near real-time hurricane forecast—The University of Utah group, *HFIP annual review meeting*, November 9-10, 2010, Miami, FL.